Journal of Food Innovation, Nutrition, and Environmental Sciences
March, 2026, Volume 3; Issue 1:46-57
ISSN No:3078-5537

ORIGINAL RESEARCH ARTICLE

Comparative Effects of Natural and Alternative Ripening Inducers on the Nutritional Qualities of Plantain Flours

Oladebeye Aderonke Adenike[1], Oladebeye Abraham Olasupo[2]*, and Adelu Akeem Olalekan [1]

[1]Department of Food Technology, School of Applied Sciences and Technology, Auchi Polytechnic Auchi, Edo State, Nigeria
[2]Department of Science Laboratory Technology, University of Medical Sciences, Ondo, Nigeria
DOI: https://doi.org/10.70851/jfines.2026.3(1).46.57

Article history
Received;
24 December, 2025
Revised;
24 February, 2026
Accepted;
28 February, 2026

Keywords
Artificial ripening inducers.
Phytochemicals,
Antioxidants,
Reduced sugars

ABSTRACT
This study was aimed at comparing the effects of natural and alternative ripening agents, namely natural ripening, calcium carbide, cassava peel, and unripe wild mango, on the nutritional attributes of plantain (*Musa paradisiaca*) under a completely randomized design. All the nutritional parameters studied were significantly different ($p < 0.05$). Natural ripened plantain flour (NRPF) sample exhibited the highest proximate values in terms of moisture (4.53%), crude fat (6.18%), crude fibre (2.85%), crude protein (5.91%), and ash (4.17%), while the peak carbohydrate by difference (84.42%) was obtained in calcium carbide–treated plantain flour (CCTPF) sample. Potassium concentration was highest (76.38 mg/100g) in cassava peel–treated plantain flour (CPTPF) sample, lowest in CCTPF sample (49.20 mg/100g) whereas the peak concentration of calcium (64.63 mg/100g) was obtained in CCTPF sample. The highest sugar concentrations of sucrose (82.48 g/100g), fructose (93.50 g/100g), and glucose (84.22 g/100g) were obtained in CPTPF, while the lowest sucrose content (74.88 g/100g), and highest phytochemical levels in terms of phytate (5.94 mg/100 g), oxalate (15.69 mg/100g), tannins (0.58 mg100/g), and phytic acid (1.67 mg/100 g) were exhibited by CCTPF sample. The scavenging potentials of DPPH, flavonoids and total phenols as antioxidants were most prominent in the NRPF sample, and least prominent in CCTPF sample. Sensory attributes of the samples ranked in the descending order: NRPF > unripe mango-treated plantain flour (UMTPF) > CPTPF > CCTPF in terms of aroma, taste, chewiness, firmness greasiness and general acceptability. In conclusion, natural and bio-based ripening methods preserved the nutritional qualities of the samples studied whereas calcium carbide, as an artificial ripening inducer, negatively degraded the nutritional qualities.

.

*Corresponding author
E-mail: aooladebeye@unimed.edu.ng (Oladebeye, Abraham O.)
Peer review under responsibility of Journal of Food Innovations, Nutrition, and Environmental Sciences.

A Publication of EcoScribe Publishers company Limited, Uganda.

1. INTRODUCTION

Plantain (*Musa paradisiaca*) is one of the most important starchy staples cultivated in tropical regions, particularly in West Africa, playing a central role in food security, income generation, and dietary diversity. Carbohydrates, dietary fibre, potassium, and essential micronutrients are significantly pronounced in plantain, when consumed fresh or processed into flour, snacks, and traditional meals (Odebode, 2021; FAO, 2022). Plantain is highly perishable due to its ripening behaviour, from senescence to postharvest deterioration, especially under high temperature and humidity in tropical regions (Irtwange *et al*., 2023).

Fruit traders, however depend on induced ripening practices to mitigate the rapid spoilage of plantain and meet market demands. Natural ripening, which may take 5–10 days depending on ambient conditions, is often considered too slow for commercial turnover, leading to the use of chemical and biological ripening agents. Calcium carbide remains one of the most commonly applied due to its low cost and efficiency. When in contact with water molecules from moisture, calcium carbide releases acetylene gas, which initiates ripening responses resembling those of ethylene. However, acetylene lacks the regulatory specificity of endogenous ethylene and may disrupt coordinated metabolic processes during fruit maturation (Agoreyo *et al*., 2021). In addition, industrial calcium carbide commonly contains arsenic and phosphide impurities, raising serious concerns regarding consumer safety and long-term health risks (WHO, 2022; Okoye *et al*., 2023). A study on the health risks of using chemical inducers, such as calcium carbide to ripen fruits in Nigeria has been reported (Ekanem *et al.*, 2021). The use of calcium carbide by fruit vendors for quick ripening and huge profit has been condemned by National Agency for Food and Drug Administration and Control (NAFDAC), and subsequently banned by Federal Competition and Consumer Protection (FCCPC) (Orok *et al.*, 2024).

In light of the health risks associated with chemical ripening agents, increasing attention has turned to safer, natural alternatives such as unripe wild mango (*Irvingia gabonensis*), traditionally employed in some West African communities, and cassava peel (*Manihot esculenta*), which generates ethylene naturally through microbial activity (Okonkwo *et al*., 2020; Adeyeye and Adebayo, 2022). These options are environmentally sustainable, locally accessible, and cost-effective; however, evidence on their comparative efficiency and effects on fruit quality remains scarce. Notably, the use of wild mango, locally known as 'Dukanut,' is gaining attention due to its dual role in facilitating ripening and enhancing nutritional content, yet it remains insufficiently studied within modern postharvest systems (Okorie *et al*., 2023).

This study, therefore investigated, under controlled conditions, how chemical ripening with calcium carbide compares with natural and bio-based ripening methods using cassava peel and unripe wild mango. Emphasis was placed on evaluating variations in proximate compositions, mineral contents, vitamins, antioxidants, phytochemicals, and consumer-relevant sensory attributes of ripened plantain.

2. MATERIALS AND METHODS

2.1 Sample collection

Mature unripe plantains were harvested from a local farm within the premises of Auchi Polytechnic, Auchi, Etsako-West Local Government Area, Edo State, Nigeria. Wild mango fruits were obtained from a farm at Ibienafe, South-Ibie, and cassava peels from a traditional cassava processing site at Ibienafe, South-Ibie, Etsako-West Local Government Area, Edo State, Nigeria. Calcium carbide was purchased from Turraco Industrial Limited, Lagos, Nigeria.

2.2 Sample preparation

A completely randomized design was employed to evaluate four ripening methods applied to uniform batches of mature green plantains. Natural ripening was ensured under ambient conditions. For chemical ripening, 2 g of calcium carbide was applied to 2 kg of the unripe plantains, in line with local commercial practice (Igbinaduwa *et al*., 2022). Biological ripening treatments involved either burying plantains in fresh cassava peels to utilize naturally evolved ethylene or co-storing plantains with unripe wild mango fruits at a 1:1 fruit-to-kilogram ratio. All treatments were conducted in perforated cardboard cartons at 28±2 °C for five days to prevent direct contact. Ripening progression was confirmed by visual colour transition of the peels from green to yellow prior to analysis (Gandhi ***et al***., 2016). Following ripening, the plantains were sliced, oven-dried at 60 °C for 48 h, milled into fine flour, and stored in airtight containers prior to analysis (Oko ***et al.***, 2018). The samples were identified as NRPF (natural ripened plantain flour), CCTPF (calcium carbide-treated plantain flour), UMTPF (unripe mango-treated plantain flour)**,** and CPTPF (cassava peel-treated plantain flour).

2.3 Proximate analysis

The proximate compositions of the samples studied were analyzed following AOAC analytical procedures (AOAC, 2019) with slight modification. The carbohydrate contents were determined by difference (100 minus the sum of other components).

2.4 Mineral analysis

The mineral concentrations of the samples were evaluated using spectrometric techniques described by AOAC (AOAC, 2016). The concentrations of potassium and sodium were evaluated using a flame photometer (Corning, EEL), while calcium, magnesium, iron, and zinc were determined with an atomic absorption spectrophotometer (Model 205, Buck Scientific, USA). Total phosphorus was further measured by the phospho-vanadomolybdate method at 430 nm using a UV/visible spectrophotometer (Jenway 7305, UK).

2.5 Antioxidant activities

2.5.1 Total Phenol content determination

The total phenolic contents of the flour samples were determined using the standard methods of Folin–Ciocalteu described by Oluwadamilare *et al*. (2025) and Singleton *et al*. (1999). Briefly, 20 g of each flour sample was soaked in methanol:water (80:20, v/v (mL)) for 24 h, and the filtrate was concentrated at 40 °C under vacuum using a rotary evaporator. Then, 50 mL of aqueous extract solution was dispensed into a test tube, holding 50 µL of distilled water, and 500 µL of Folin–Ciocalteu reagent was added into the test tube and shaken thoroughly. After 3 min, 400 µL of 7.5% sodium carbonate solution was added and the mixture was incubated at 45 ºC in a water bath for 40 min. Absorbance was measured at 765 nm against blank. The same procedure was repeated to all standard gallic acid solutions (0.1 mg/mL). The total phenolic content was expressed as gallic acid equivalent per gram of sample (mg of GAE/g sample) through the calibration curve of gallic acid and calculated as follows;

$$\textbf{Total phenolic content (mgGAE/g)} = \frac{\text{Abs.}_{\text{sample}} \times \text{Conc.}_{\text{standard}}\ (\text{mg/mL})}{\text{Abs.}_{\text{standard}} \times \text{Conc.}_{\text{sample}}\ (\text{mg/g})}$$

2.5.2 Total Flavonoid content determination

The total flavonoid content was determined using a modified method described by Quettier-Deleu *et al*. (2000). The methanolic extract of plantain flour (2 mL) was mixed with 2 mL of 2% methanolic aluminum chloride ($AlCl_3 \cdot 6H_2O$). After 10 min of incubation, the absorbance of the resulting brown solution was measured at 430 nm using a UV–visible spectrophotometer (model 1800, Shimadzu, Japan). Flavonoid content was expressed as mg/100g of flour.

2.5.3 DPPH activities

The method described by Oluwadamilare *et al.* (2025) was adopted to determine the 1,1-Diphenyl-2-picryhydrazyl (DPPH) radical scavenging activity. The phenolic extract of each sample was mixed with 1 mL of 0.4 mmol/L DPPH methanolic solution and incubated in the dark for 30 min. The absorbance of the resulting solution was measured at 516 nm using a UV-visible spectrophotometer (model 1800, Shimadzu, Japan). The percentage DPPH radical scavenging activity was calculated as follows:

$$\textbf{DPPH radical scavenging activity (\%)} = \frac{A_{\text{control}} - A_{\text{testl}}}{A_{\text{control}}} \times 100$$

2.6 Phytochemical compositions

2.6.1 Phytate content determination

The method of Haug and Lantzsch (1983), modified by Oluwadamilare *et al*. (2025) was adopted to determine the phytate concentrations of the samples studied. Briefly, 0.1 g of the sample was extracted with 10 mL of 0.2 mol/L HCl and was shaken for 30 min. A portion of the extract (1 mL) was then dispersed in 2 mL of ferric solution in a stoppered test tube and equilibrated to room temperature in a water bath. Subsequently, 4 mL of 2,2′-bipyridine solution was added, thoroughly mixed, and the absorbance of the mixture was measured at 519 nm.

2.6.2 Oxalate content determination

The oxalate contents of the samples were determined by adopting the method described by Abou-Arab and Abu-Salem (2017). Concisely, 2.0 g of plantain flour was digested in a volumetric flask with 6 mol/L HCl for 1 h. The filtrate was treated with concentrated ammonium hydroxide until a faint yellow color appeared, before that addition of 10 mL of 5% calcium chloride. The resulting mixture was centrifuged at 2,500 rpm to precipitate the insoluble oxalate, which was then dissolved in 10 mL of 20% tetraoxosulphate (vi) acid. The solution was diluted to 300 mL and titrated against standardized 0.01 mol/L potassium permanganate until a persistent light-pink endpoint (≈30 s) was observed.

2.6.3 Tannin content determination

The tannic contents of the samples were determined using the method described by Medoua *et al.* (2007). Two (2) grams of each sample were weighed into a 250 ml flask followed by the addition of 200 ml of 0.004 M $K_3Fe(CN)_6$ and 10 ml of 0.008 M $FeCl_3$ in 0.008 M HCl. The flask was allowed to stand for 20 minutes and stirred occasionally at 10 min intervals and 1 ml aliquot was removed. To this aliquot was added 2 ml of 0.008 M $FeCl_3$ in 0.008M HCl and 10 ml of 0.0015 M $K_3Fe(CN)_6$. After adding the final reagent, the absorbance was then read at 720 nm after 30 seconds against a blank.

$$\textbf{Tannin (mg/100g)} = \frac{A_{sample} \times C \times D_f}{A_{standard} \times W}$$

where, A_{sample} = absorbance of sample; $A_{standard}$ = absorbance of standard; C = concentration of standard; D_f = dilution factor; W = sample weight

2.7 Vitamin analyses

2.7.1 Determination of Vitamin A

The method of Olubiyo *et al.* (2022) was adopted to determine the vitamin A (β-carotene) contents of the samples. This was carried out by extracting 1 g of plantain flour in 5 mL of methanol for 2 h at room temperature in the dark to ensure complete extraction. The β-carotene fraction was separated using hexane in a separating funnel, and the volume was adjusted to 10 mL with hexane. The extract was passed through sodium sulfonate to remove residual moisture, and the absorbance was measured at 436 nm using hexane as the blank. β-carotene concentration was then calculated using the formula below and expressed as **µg/100g**

$$\boldsymbol{\beta - \text{carotene}} = \frac{\textbf{Absorbance} \times \mathbf{V} \times \mathbf{D}}{\boldsymbol{W} \times \boldsymbol{Y}} \times \mathbf{100}$$

where, V = Total volume of extract; D= Dilution factor; W = Sample weight; Y = Percentage dry matter content of the sample

2.7.2 Determination of Vitamin C

Vitamin C content was analyzed according to the procedure described by Olubiyo *et al*. (2022). Briefly, 10 g of the sample was extracted with 50 mL of EDTA/TCA solution (50 g in 50 mL of water) for 1 h, after which the mixture was filtered through Whatman filter paper into a 50 mL volumetric flask and diluted to volume with the extracting solution. An aliquot of 20 mL of the filtrate was transferred into a 250 mL conical flask, followed by the addition of 10 mL of 30% KI and 50 mL of distilled water to the flask. Subsequently, 2 mL of 1% starch indicator was added, and the solution was titrated with 20% $CuSO_4$ solution until a dark end-point was observed.

2.8 Sugars analysis

Approximately 0.5 g (dry weight) of each plantain flour sample was placed in a 50 mL centrifuge tube and extracted with 25 mL of 80% (v/v) ethanol. The mixture was vortexed, shaken at 200 rpm for 30 min at 60 °C, and centrifuged at 4000 ×g for 10 min. The pellet was subjected to two additional extractions under identical conditions. All supernatants were collected, adjusted to approximately 50 mL with 80% ethanol, and concentrated under reduced pressure at ≤40 °C to remove the solvent. The remaining aqueous solution was quantitatively transferred to a 25 mL volumetric flask and diluted with ultrapure water (UPW). The extracts were allowed to pass through 0.45 µm PTFE syringe filters of high-performance liquid chromatography, equipped with a refractive index detector (HPLC–RID), an Aminex HPX-87P column (300 × 7.8 mm) fitted with a guard column (Bio-Rad) maintained at 80 °C, and a mobile phase, consisting of degassed UPW isocratically delivered at a flow rate of 0.6 mL/min (AOAC, 2019; Nielsen, 2017). A 20 µL injection volume was used. Calibration curves for sucrose, D-glucose, and D-fructose (≥99% purity) were prepared in water over the concentration range of 0.05–5.00 g/L, with linearity accepted at $R^2 \geq 0.999$. Lactose (1.0 g/L) was used as an optional internal standard to monitor the consistency of the injection. Peaks were identified by retention time matching (±0.1 min) and further verified through standard addition to representative samples. Concentrations (g/100g, dry basis) were obtained from calibration curves and corrected for dilution factors as follows:

$$\textbf{Sugar (g/100g)} = \frac{C_{HPLC} \times V_{final}}{\text{Sample weight}} \times 100$$

where, C_{HPLC} = measured concentration in the injected extract and V_{final} = final extract volume

2.9 Sensory evaluation

Natural ripened and alternative ripened plantain fingers were washed with potable water to remove dirts, peeled manually using a stainless steel knife, and uniformly sliced to 1 cm thickness to ensure uniform heat transfer. Salt was not added to prevent blinding the taste of the products. Vegetable oil (King Oil brand) was poured into a frying pan and heated to a temperature of 170 °C for deep frying. The plantain slices were introduced into the hot oil in batches to prevent overcrowding, and were fried for 10 mins until golden brown. The fried samples were removed using a slotted spoon, drained on absorbent paper to remove excess oil, and cooled to room temperature before sensory evaluation. The sensory characteristics, aroma, taste, chewiness, firmness, greasiness, and general acceptability of the fried plantain samples were assessed by 10 semi-trained panelists using the nine-point hedonic scale, ranging from 1 = dislike extremely to 9 = like extremely (Meilgaard *et a*l., 2007; Stone and Sidel, 2004).

2.10 Statistical analysis

All analyses were conducted in triplicate, and data were subjected to analysis of variance using SPSS (v23.0). Duncan's New Multiple Range Test (DNMRT) was used to separate the means at p<0.05 significant difference.

3. RESULTS AND DISCUSSION

3.1 Proximate compositions

Table 1 shows the proximate compositions of natural and artificial ripened plantain flour samples. Natural ripened plantain flour (NRPF) sample exhibit the highest contents of moisture (4.53%), ash (4.17%), crude fat (6.18%), crude fibre (2.85%), crude protein (5.91%), while calcium carbide–treated plantain flour (CCTPF) sample shows the lowest corresponding values, except for carbohydrate by difference. The reduction in proximate parameters observed in CCTPF sample can be adduced to the accelerated ripening caused by acetylene gas released when calcium carbide comes in contact with moisture, thereby distrupting normal enzymatic and biosynthetic pathways responsible for nutrient accumulation (Maduwanthi and Marapana, 2019). This observation has been reported for several fruits, where ripening is attained by calcium carbide treatment (Ugbeni *et al*., 2023; Akinyemi *et al*., 2020). In contrast, cassava peel-treated plantain flour (CPTPF) sample possesses higher contents of ash, crude protein and carbohydrate than the unripe mango-treated plantain flour (UMTPF) sample.

Table 1. Proximate compositions of natural and alternative ripened plantain flour samples

Sample	Moisture Content (%)	Ash Content (%)	Crude Fat (%)	Crude Fibre (%)	Crude Protein (%)	Carbohydrate (%)
NRPF	4.53^{a}±0.04	4.17^{a}±0.05	6.18^{a}±0.03	2.85^{a}±0.03	5.91^{a}±0.04	76.36^{d}±0.19
CCTPF	3.91^{d}±0.02	2.87^{d}±0.06	3.18^{d}±0.03	1.94^{d}±0.00	3.68^{d}±0.01	84.42^{a}±0.03
UMTPF	4.46^{b}±0.04	3.46^{c}±0.06	4.99^{b}±0.01	2.62^{b}±0.00	4.58^{c}±0.01	79.89^{c}±0.01
CPTPF	4.25^{c}±0.04	4.06^{b}±0.04	3.90^{c}±0.14	2.07^{c}±0.06	5.14^{b}±0.03	80.58^{b}±0.12

Values are means ± standard deviation. (n = triplicate). Different superscripts within a column indicate significant differences ($p < 0.05$). NRPF = Natural ripened plantain flour, CCTPF = calcium carbide-treated plantain flour, UMTPF = unripe mango-treated plantain flour and CPTPF = cassava peel-treated plantain flour

These results obtained imply that bio-based ripening agents, such as cassava peels and unripe mango peels, ensure a more gradual biochemical formation and transformation, facilitating enhanced nutrient retention and sustained structural integrity (Islam *et al.,* 2020). However, high contents of crude fibre and crude fat in NRPF sample are contributions to improved digestibility and stored energy (Wills *et al*., 2019). These findings reveal that natural ripening optimizes nutrient development and sustains compositions, whereas calcium carbide markedly impairs nutritional quality, making cassava peels and unripe mango peels safer and nutritionally advantageous alternatives for ripening.

3.2 Mineral composition

Table 2 presents the mineral compositions of natural and alternative ripened plantain flour samples studied. Among all the minerals, the most abundant is potassium with the peak value (76.38 mg/100g) obtained in CPTPF sample, and the least (49.20 mg/100g) in CCTPF sample. The peak value of potassium (K) in CPTPF sample may not be unconnected to the relative abundance of potassium in the cassava peels (Chua *et al.,* 2020) used as ripening inducers. The stability of K during ripening due to its role in intracellular cation resistance to volatilization and oxidation has been reported (Adepoju *et al*., 2023). In the same vein, CCTPF sample is conspicuously high in calcium (Ca) content (64.63 mg/100g). This observation can be adduced to the possible leaching of calcium from calcium carbide to the plantain fruits.

Table 2. Mineral compositions of natural and alternative ripened plantain flour samples

Sample	Mineral (mg/100g)						
	Sodium	Potassium	Magnesium	Calcium	Phosphorus	Zinc	Iron
NRPF	17.96^{c}±0.12	65.99^{b}±0.02	28.03^{c}±0.02	41.43^{c}±0.06	10.57±0.02	1.75^{a}±0.01	1.45^{a}±0.01
CCTPF	19.99^{a}±0.13	49.20^{d}±0.34	28.11^{b}±0.01	64.63^{a}±0.02	9.53^{d}±0.02	1.10^{d}±0.01	0.45^{c}±0.04
UMTPF	19.40^{b}±0.22	50.09^{c}±0.02	28.33^{a}±0.01	19.78^{d}±0.22	9.76^{c}±0.08	1.52^{b}±0.03	0.47^{c}±0.02
CPTPF	16.44^{d}±0.01	76.38^{a}±0.02	27.19^{d}±0.07	45.04^{b}±0.03	12.65^{a}±0.01	1.22^{c}±0.03	1.05^{b}±0.02

**Dry basis; Mean±SD in the same column with different superscripts are significantly different at 5% level with a > b > c > d. Mean separation done by Duncan Multiple Range Test.* NRPF = Natural ripened plantain flour, CCTPF = calcium carbide-treated plantain flour, UMTP = unripe mango-treated plantain flour and CPTPF = cassava peel-treated plantain flour

The NRPF sample exhibits the highest concentrations of zinc (1.75 mg/100g) and iron (1.45 mg/100g), but are surpassed by UMTPF sample in terms of sodium content (19.40 mg/100g) and magnesium content (28.33 mg/100g), and by CPTPF sample in terms of potassium content (76.38 mg/100g), calcium content (45.04 mg/100g) and phosphorus content (12.65 mg/100g). These findings are in support of the observation that natural ripening supports optimal enzymatic regulation and minimizes nutrient degradation, resulting in superior mineral retention (Oyeleke *et al.,* 2020). The variations in mineral concentrations observed among alternative ripened samples could be associated with the induced metabolic disruptions and enhanced moisture content, leading to nutrient dilution or complexation reactions between ripening agents and cellular components (Sojinu *et al.,* 2021; Zou *et al.*, 2022).

The drop in both iron and zinc contents of CCTPF sample compared to NRPF sample may poses nutritional concerns, given the roles of these elements in preventing anemia and supporting immune function (Gibson and Ferguson, 2018; Chondrou *et al.,* 2024). Moreover, the use of calcium carbide, although effective in accelerating ripening, can introduce harmful residues such as arsenic and phosphide impurities, rendering CCTPF sample unsafe for food consumption and applications (Okeke, 2022; Ugbeni *et al*., 2023; Deshi, 2024).

3.3 Sugar composition

Table 3 depicts the sugar compositions (sucrose, fructose, and glucose) of the natural and alternative ripened plantain flour samples. CPTPF sample records the highest concentrations of all sugars: sucrose (82.48±0.11 g/100g), fructose (93.50±0.17 g/100g), and glucose (84.22±0.19 g/100g). The lowest content of sucrose (74.88 g/100g) and glucose (78.44 g/100g) contents are found in the CCTPF sample, while the UMTPF sample show moderate sucrose and fructose contents, but a relatively lower glucose content. The contents of sucrose (77.03 g/100g), fructose (82.66 g/100g), and glucose (79.23 g/100g) in NRPF sample may actually indicate a balanced sugar composition compared to the alternative ripened samples. Ripening process tends to accumulate sucrose, fructose and glucose via the enzymatic hydrolysis of starch by α- and β-amylases (Khawas *et al*., 2016; Saranraj and Sivasakthi 2018). Natural ripening accounts for the gradual conversion and stabilization of sugars, whereas chemical ripening processes often impair the rate and balance of these pathways.

The significantly higher sugar content in the CPTPF sample suggests that bio-based ripening agents enhance enzymatic starch degradation, possibly due to ethylene-like compounds or microbial metabolites that stimulate carbohydrate metabolism (Maduwanthi and Marapana, 2019). Ethylene and its analogs activate invertase and sucrose synthase, leading to increased sucrose hydrolysis into fructose and glucose (Seymour *et al.,* 2013). The pronounced increase in fructose and glucose contents in the CPTPF sample is an indication of the complete conversion of complex carbohydrates, resulting in sweeter fruit with enhanced palatability. Conversely, the CCTPF sample exhibits the lowest sucrose and glucose contents, indicating incomplete starch-to-sugar conversion. This observation may not be unconnected to acetylene gas released by calcium carbide, which imitates the physiological role of ethylene, but lacks the biochemical precision of ethylene in regulating ripening enzymes (Kumar *et al*., 2017). Studies on banana and mango have shown that calcium carbide–induced ripening often leads to uneven softening and sub-optimal sugar accumulation compared to natural ripening (Rahman *et al.,* 2018; Chattopadhyay *et al.,* 2021). The limited glucose concentration in the CCTPF sample may therefore result from inhibited activities of α- and β-amylases and invertases, leading to premature termination of the ripening process.

Table 3. Sugar compositions and vitamin profiles of natural and alternative ripened plantain flour samples

Sample	Sugars (g/100g)*			Vitamin (µg/100g)*	
	Sucrose	Fructose	Glucose	A	C
NRPF	77.03^{c}±0.14	82.66^{d}±0.05	79.23^{b}±0.14	1952.86^{a}±4.82	18.67^{a}±0.06
CCTPF	74.88^{d}±0.11	84.07^{b}±0.12	78.44^{c}±0.14	1835.99^{d}±0.23	16.03^{d}±0.03
UMTPF	77.45^{b}±0.04	83.24^{c}±0.23	73.64^{d}±0.14	1863.86^{b}±0.04	16.74^{b}±0.01
CPTPF	82.48^{a}±0.11	93.50^{a}±0.17	84.22^{a}±0.19	1842.89^{c}±2.49	16.27^{c}±0.03

**Dry basis; Mean±SD in the same column with different superscripts are significantly different at 5% level with a > b > c > d. Mean separation done by Duncan Multiple Range Test.* NRPF = Natural ripened plantain flour, CCTPF = calcium carbide-treated plantain flour, UMTP = unripe mango-treated plantain flour and CPTPF = cassava peel-treated plantain flour.

3.4 Vitamin compositions

The vitamin compositions are as shown in **Table 3**. NRPF sample possesses the highest concentrations of vitamins A and C (1952.86 µg/100g and 18.67 µg/100g) respectively, followed by UMTPF sample (1863.86µg/100g and 16.74 µg/100g), and least in CCTPF sample (1835.99 µg/100g and 16.03 µg/100g). The drop in vitamin levels among the samples, NRPF > UMTPF > CPTPF > CCTPF, suggests that alternative ripening to natural ripening, particularly with calcium carbide, adversely affects the retention of vitamins A and C, due to the disruption of natural metabolic and enzymatic pathways responsible for the biosynthesis and stabilization of carotenoids (vitamin A precursors) and ascorbic acid (vitamin C). These observations are in line with observations documented for ripening-induced biochemical processes (Olubiyo *et al.*, 2022; Gbakon *et al.*, 2018). This is with the view that natural ripening proceeds gradually, allowing optimal enzymatic regulation to support the accumulation and preservation of these vitamins (Maduwanthi and Marapana, 2019; Rahman *et al*., 2018).

3.5 Sensory attributes

The results of the sensory attributes of natural and alternative ripened plantain flour samples are shown in **Table 4**. NRPF sample has the highest general acceptability (8.90), followed by CPTPF sample (8.60) and lowest (7.00) in CCTPF sample. The sensory aroma, taste, chewiness, firmness and greasiness of the flour samples range from 8.00 (CPTPF) to 8.70 (NRPF), 7.70 (CCTPF) to 8.80 (NRPF), 7.80 (CCTPF) to 8.90 (NRPF), 7.30 (CCTPF) to 8.70 (NRPF/CPTPF) and 7.10 (UMTPF) to 8.80 (NRPF) respectively. It is obvious that the use of calcium carbide to induce ripening of plantain negatively alters and impairs the sensory attributes of the fruits. CCTPF sample stands no chance as an alternative ripening inducer that maintains nutritional composition and sustains structural integrity compared to natural ripening method and bio-based ripening inducers.

Table 4. Sensory attributes of fried of natural and alternative ripened plantain samples

Sample	Aroma	Taste	Chewiness	Firmness	Greasiness	General Acceptability
NRPF	$8.70^{a}\pm0.48$	$8.80^{a}\pm0.42$	$8.90^{a}\pm0.32$	$8.70^{a}\pm0.48$	$8.80^{a}\pm0.42$	$8.90^{a}\pm0.32$
CCTPF	$7.80^{b}\pm1.03$	$7.70^{b}\pm1.06$	$7.80^{b}\pm1.32$	$7.30^{b}\pm1.06$	$7.30^{b}\pm0.67$	$7.00^{b}\pm1.33$
UMTPF	$8.50^{ab}\pm0.53$	$8.30^{ab}\pm1.16$	$8.40^{ab}\pm1.07$	$8.60^{a}\pm0.70$	$7.10^{b}\pm1.52$	$7.30^{b}\pm0.95$
CPTPF	$8.00^{ab}\pm0.82$	$8.40^{ab}\pm0.70$	$8.50^{ab}\pm0.71$	$8.70^{a}\pm0.48$	$8.30^{a}\pm0.82$	$8.60^{a}\pm0.70$

Mean±SD in the same column with different superscripts are significantly different at 5% level with a > b > c > d. Mean separation done by Duncan Multiple Range Test. NRPF = Natural ripened plantain flour, CCTPF = calcium carbide-treated plantain flour, UMTP = unripe mango-treated plantain flour and CPTPF = cassava peel-treated plantain flour.

3.6 Phytochemical Compositions

Figure 1 depicts the phytochemical profile of natural and alternative ripened plantain flour samples, showing significant variations ($p < 0.05$) in phytate, oxalate, tannin, and phytic acid contents. CCTPF sample exhibits the highest concentrations of phytate (5.94 mg/100g), oxalate (15.69 mg/100g), tannins (0.58 mg/100 g), and phytic acid (1.67 mg/100 g). The elevated levels in the CCTPF sample could result from the accelerated ripening process, which disrupts enzymatic homeostasis and oxidative metabolism, leading to impaired degradation and high synthesis of phytochemicals. Other studies have shown that calcium carbide ripening process alters normal fruit metabolism by simultaneously reducing vitamin concentration while increasing phytochemical accumulation (Ugbeni *et al.*, 2023; Maduwanthi *et al.*, 2019). CPTPF sample possesses moderately high phytochemical values, followed by the UMTPF sample, while the NRPF sample contains the lowest levels of phytate (4.12 mg/100 g), oxalate (10.98 mg/100 g), tannin (0.35 mg/100 g), and phytic acid (1.16 mg/100 g). The variations observed in bio-based ripening induced flour samples, CPTPF and UMTPF, could be due to their ethylene-like activity, which facilitates a more controlled and natural ripening process (Maduwanthi *et al.*, 2019). Overall, this present study provides findings that indicate that natural ripening promotes a more stable biochemical transformation, minimizing phytochemical accumulation compared with alternative ripening methods.

*3.*7 Antioxidant Profiles

Antioxidants are considered important nutraceuticals because they scavenge free radicals generated in the body during metabolic processes (Badejo e*t al.*, 2017). The antioxidant assessment of the plantain samples demonstrates significant ($p < 0.05$) differences in DPPH radical scavenging capacity, flavonoid concentration, and total phenolic content, indicating that the ripening approach markedly influences the antioxidant integrity of the fruit (**Figure 2**). NRPF sample exhibits the highest antioxidant parameters, DPPH (38.45%), flavonoids (35.72 mg100/g), and total phenols (14.67 mgGAE/g, dwb), which are indicative of enhanced biosynthesis and preservation of bioactive phytochemicals with potent antioxidant functionality. Conversely, CCTPF sample presents the lowest antioxidant indices, underscoring the detrimental impact of calcium carbide ripening on phenolic metabolism and oxidative stability. The drop in antioxidant potential is not unconnected to accelerated and physiologically unbalanced ripening induced by acetylene gas, leading to oxidative degradation of phenolic and flavonoid constituents (Maduwanthi and Marapana, 2019; Ugbeni *et al.*, 2023). UMTPF and CPTPF samples exhibit moderate antioxidant activities, with UMTPF sample better than CPTPF sample. This pattern suggests that bio-based ripening agents that contain natural ethylene analogs and antioxidant compounds, such as unripe mango, foster a more gradual and biochemically balanced ripening process, thereby enhancing the stability and sustainability of phenolic metabolites (Islam *et al.*, 2020). The findings of this study confirm that natural ripening preserves antioxidant integrity, while calcium carbide severely compromises the bioactive quality of plantain. In contrast, the use of bio-based ripening inducers such as unripe mango and cassava peel provides safer, more nutritionally sustainable alternatives for achieving effective fruit ripening.

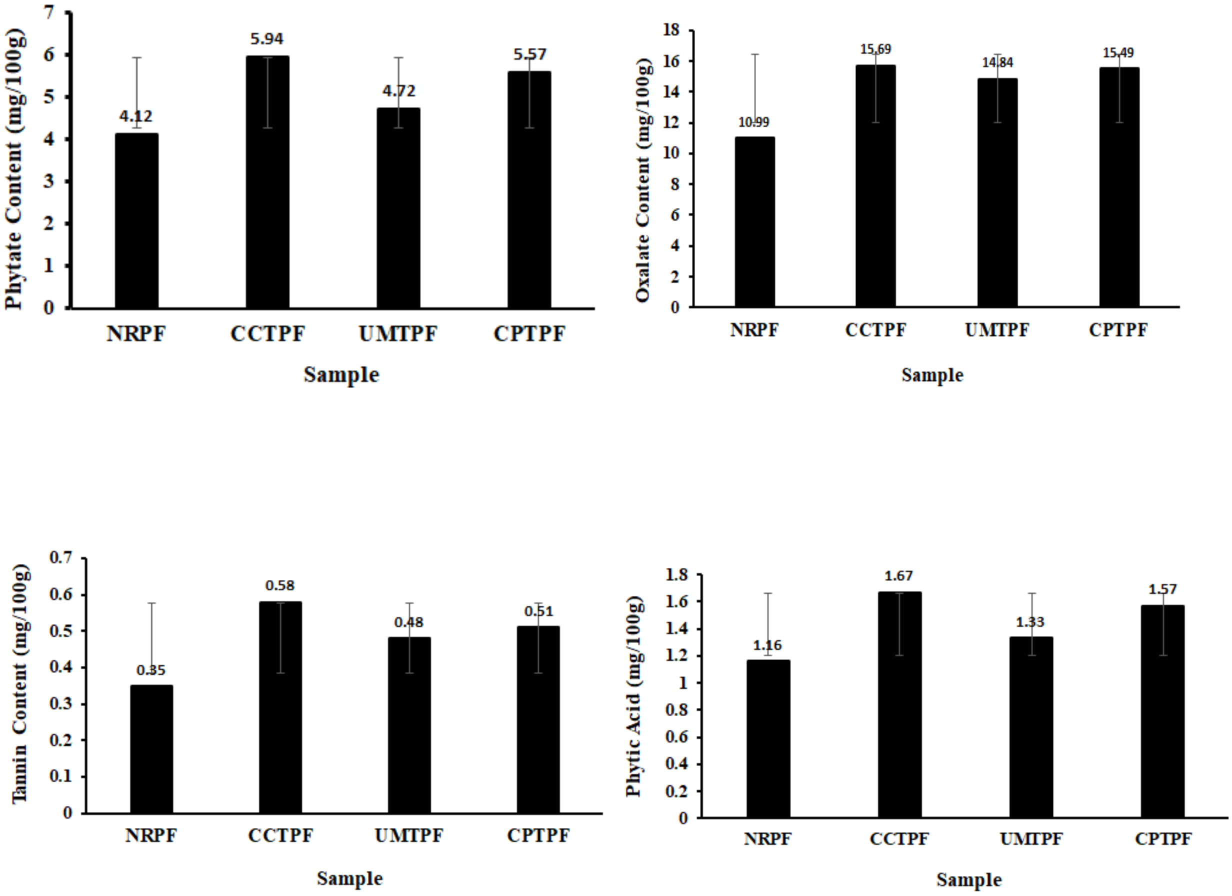
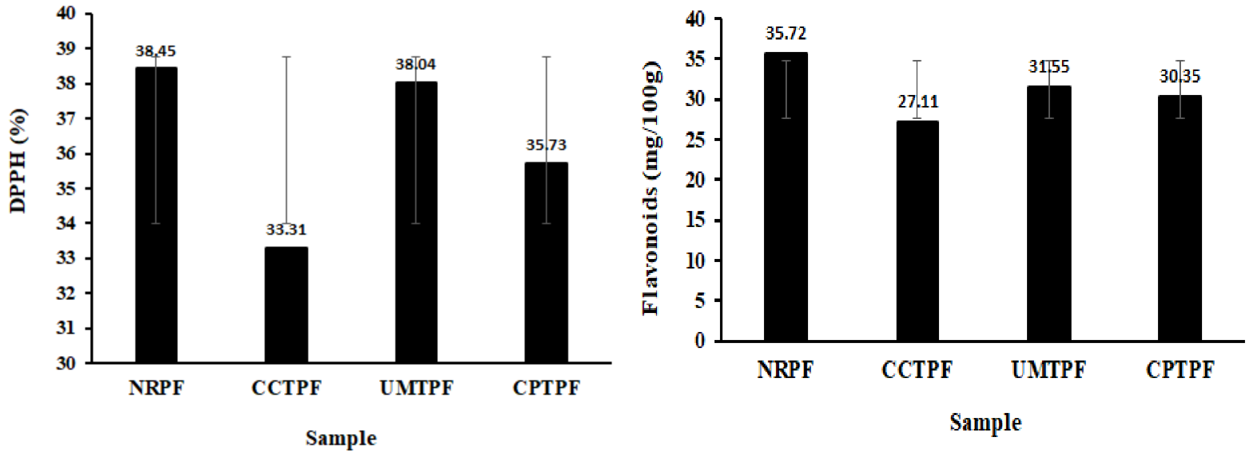


Figure 1. Phytochemical compositions of natural and alternative ripened plantain flour samples
Values are mean±SD. NRPF = Natural ripened plantain flour, CCTPF = calcium carbide-treated plantain flour, UMTP = unripe mango-treated plantain flour and CPTPF = cassava peel-treated plantain flour



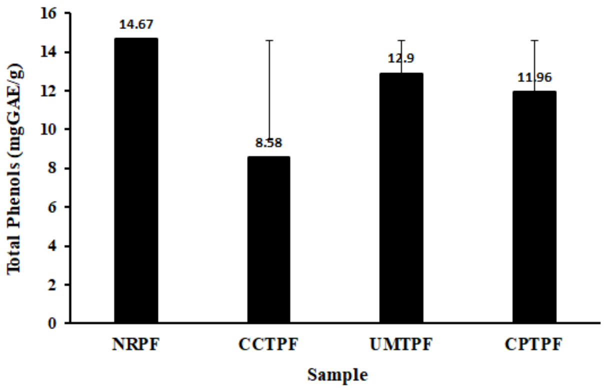


Figure 2. Antioxidants of natural and alternative ripened plantain flour samples
Values are mean±SD. NRPF = Natural ripened plantain flour, CCTPF = calcium carbide-treated plantain flour, UMTP = unripe mango-treated plantain flour and CPTPF = cassava peel-treated plantain flour

CONCLUSION

This study has revealed the effects of natural ripening process and alternative ripening agents, namely: calcium carbide, unripe mango peels and cassava peels on the nutritional qualities of plantain flours. Natural ripening method sustains proximate and mineral compositions, enhances vitamin functionality, maintains antioxidant activities, and lowers phytochemical potentials. Bio-based ripening agents, such as unripe wild mango and cassava peel studied, support a more physiologically regulated ripening process, resulting in moderate nutrient preservation and improved metabolic stability compared to calcium carbide ripening method. Cassava peel also promotes enhanced sugar development, indicating efficient enzymatic starch degradation. Conversely, calcium carbide compromises nearly all the measured quality parameters, including reductions in minerals, vitamins, and antioxidants, but favours increase in phytochemicals. These findings reveal that natural ripening optimizes nutrient development and sustains compositions, whereas calcium carbide markedly impairs nutritional quality, making cassava peels and unripe mango peels safer and nutritionally advantageous alternatives for ripening for postharvest food and non-food uses. This study therefore recommends bio-based ripening agents, such as unripe mango peels, and cassava peels, as sustainable, nutritionally beneficial, and health-conscious alternatives for natural plantain ripening in domestic and commercial systems.

ACKNOWLEDGEMENT

Authors acknowledge every individual that voluntarily contributed in one way or the other, especially in the sensory analysis.

CONFLICT OF INTEREST

Authors declare no conflicts of.

ETHICS STATEMENT

Not applicable. But, consents of all participants in the sensory analysis were obtained.

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the corresponding author.

REFERENCES

Abou-Arab A.A., & Abu-Salem F.M. (2017), Nutritional and anti-nutritional composition of banana peels as influenced by microwave drying methods, *International Journal of Nutrition*. *Food Engineering. 11, 845-852.*

Adewole, O.A., Jolayemi, O.S., Ayo-Omogie, H.N., & Badejo, A.A. (2025) Development and techno-functional characterization of gluten-free flour from rice, Cardaba banana, and pigeon-pea, *Journal of Future Foods*. https://doi.org/10.1016/j.jfutfo.2024.04.011

Adeyeye, S.A.O., & Adebayo, O.T. (2022). Natural ethylene-generating agents as alternative fruit ripening tools: A review. *Journal of Postharvest Technology*, 10(3), 45–55.

Agoreyo, F.O., Omoregie, E.S., & Eze, G.I. (2021). Comparative study of calcium carbide-ripened and naturally ripened plantain on biochemical and histopathological parameters. *Nigerian Journal of Basic and Applied Science*, 29(1), 47–55.

Akinyemi, S.O., Adeyemi, O.A., & Alamu, E.O. (2020). Effect of ripening methods on sugar profile and physicochemical properties of banana and plantain. *Journal of Food Biochemistry*, 44(5), e13189. https://doi.org/10.1111/jfbc.13189

Association of Official Analytical Chemists (AOAC) (2016). *Official methods of analysis of AOAC International* (20th ed.). AOAC International.

Association of Official Analytical Chemists (AOAC) (2019). *Official Methods of Analysis*, 21st Edition. Association of Official Analytical Chemists, Washington, D.C.

Badejo, A.A., Osunlakin, A.P., Famakinwa, A., Idowu, A.O., & Fagbemi, T.N. (2017). Analyses of dietary fibre contents, antioxidant composition, functional and pasting properties of plantain and Moringa oleifera composite flour blends. *Cogent Food and Agriculture*, 3, 1278871 http://dx.doi.org/10.1080/23311932.2017.1278871

Chattopadhyay, A., Dutta, S., & Raychaudhuri, U. (2021). Impact of ripening agents on the quality attributes of fruits: A review. *Journal of Food Science and Technology*, 58(2), 425–438. https://doi.org/10.1007/s13197-020-04526-1

Chondrou, T., Fotsis, T., & Kyratso, V. (2024). Dietary phytic acid, dephytinization, and phytase: implications for iron and zinc bioavailability. *Nutrients, 16*(23), 4069. https://doi.org/10.3390/nu16234069

Chua, M. F., Youbee, L., Oudthachit, S., Khanthavong, P., Veneklaas, E. J., & Malik, A. I. (2020). Potassium Fertilisation Is Required to Sustain Cassava Yield and Soil Fertility. *Agronomy*, *10*(8), 1103. https://doi.org/10.3390/agronomy10081103

Deshi, P. (2024). Safety evaluation of artificial fruit ripening agents: nutritional and toxicological considerations. *Journal of Food Quality and Safety, 18*(1), 112–123.

Ekanem, A. M., Sylvanus, W. N., Asanana, Q. E., Akpabio, I.-O. I., Clement, E. I., Okpara, C. K., & George, K. E. (2021). Fruit Ripening Methods and Knowledge of Health Effect of Use of Calcium Carbide in Ripening Fruits among Fruit Sellers in Uyo, Nigeria. *Journal of Advances in Medicine and Medical Research*, *33*(21), 72–83. https://doi.org/10.9734/jammr/2021/v33i2131135

FAO (2022). *Plantain and banana in West Africa: Production trends and food systems impact*. Food and Agriculture Organization of the United Nations. https://www.fao.org

Gandhi, S., Sharma, M., and Bhatnagar, B. (2016). Comparative study on the ripening ability of banana by artificial ripening agent (calcium carbide) and natural ripening agents. *Indian Journal of Nutrition,* 1(3), 5.

Gbakon, S.A., Ubwa, T.S., Ahilem, U.J., Obochi, O.G., Nwannadi, I.A., & Yusufu, M.I. (2018). Calcium Carbide Treatment on Some Physiochemical Characteristics of Broken and Mummy Mango Fruits. American Journal of Food Technology, 13(1):23-31.

Gibson, R.S., Bailey, K.B., Gibbs, M., & Ferguson, E.L. (2010). A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. *Food and Nutrition Bulletin*, 31(2 Suppl), S134–S146. https://doi.org/10.1177/15648265100312S206

Gibson, R.S., & Ferguson, E.L. (2018). Implications of phytate in plant-based diets for iron and zinc bioavailability. *Nutrition Reviews, 76*(11), 793–805. https://doi.org/10.1093/nutrit/nuy051

Haug, W., & Lantzsch, H. J. (1983). Sensitive method for the rapid determination of phytate in cereals and cereal products. *Journal of the Science of Food and Agriculture, 34*(12), 1423–1426. https://doi.org/10.1002/jsfa.2740341217

Igbinaduwa, P.O., Okeke, U.B., Dike, K.C., &. Olohigbe, A.E. (2022). Effect of calcium carbide induced ripening on the vitamin C and mineral composition of banana (*Musa acuminata*) and papaya (*Carica papaya*) fruits sourced from Benin-City, Nigeria. *West African Journal of Pharmacy (2022) 33 (1) 92-98*

Irtwange, S.V., Onuche, C.J., & Abah, E.O. (2023). Postharvest losses and artificial ripening of fruits in tropical Africa: Challenges and mitigation strategies. *African Journal of Agricultural Research*, 18(4), 104–115.

Islam, M.N., Rahman, M.M., & Ahmed, K. (2020). Natural and artificial ripening of banana: Effects on quality and biochemical composition. *Journal of Food Science and Nutrition Research*, 3(2), 104–113. https://doi.org/10.26502/jfsnr.2642-11000045

Khawas, P., Deka, S.C., & Sethi, V. (2016). Physicochemical and biochemical changes during banana (*Musa sapientum* L.) ripening. *Journal of Food Science and Technology*, 53(4), 2556–2564. https://doi.org/10.1007/s13197-016-2237-3

Kumar, R., Mishra, D.S., & Chakraborty, S. (2017). Effects of calcium carbide and ethephon on ripening and biochemical changes in mango (*Mangifera indica* L.). *International Journal of Food Science*, 2017, 1–8. https://doi.org/10.1155/2017/2436925

Lee, S. K., & Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology*, 20(3), 207–220. https://doi.org/10.1016/S0925-5214(00)00133-2

Maduwanthi, S.D.T., & Marapana, R.A.U.J. (2019). Induced ripening agents and their effect on fruit quality: A review. *Food Reviews International*, 35(6), 541–559. https://doi.org/10.1080/87559129.2018.1527371

Medoua, G.N., Mbome, I.L., Agbor-Egbe, T. and Mbofung, H. (2007). Influence of fermentation on some quality characteristics of trifoliate yam (*Dioscorea dumetorum*) hardened tubers. *Food Chemistry*, 107(3):1180-1186.

Meilgaard, M., Civille, G.V., & Carr, B.T. (2007). *Sensory Evaluation Techniques* (4th ed.). CRC Press.

Miller, J.C., Haberer, D., & Cohn, J.S. (2018). Fructose metabolism and implications for human health. *Nutrients*, 10(6), 653. https://doi.org/10.3390/nu10060653

Mokhtar, M., Bouamar, S., & Saidi, S. (2022). Relationship between phenolic content and antioxidant activity of fruit extracts: A review. *Journal of Food Quality*, 2022, 1–12. https://doi.org/10.1155/2022/5436710

Nielsen, S.S. (2017). *Food analysis* (5th ed.). Springer. (Chapters on carbohydrate extraction and HPLC-RID of sugars).

Odebode, S.O. (2021). Nutritional and economic importance of plantain in Nigerian rural communities. *African Journal of Food Science*, 15(6), 210–219.

Ojo, M.A., Olayemi, O.O., & Oluwamukomi, M.O. (2022). Tannins in foods: Nutritional implications and processing effects. *Foods*, 11(7), 988. https://doi.org/10.3390/foods11070988

Okeke, E.S. (2022). The use of calcium carbide in food and fruit ripening: a review of nutritional and toxicological issues. *Food Chemistry*. https://doi.org/10.1016/j.tox.2022.153112

Oko, A.O., Eluu, S.C., Ehihia, L.U., Nnamchi, O., Ngele K., Oluwole, A.O., Ebem E.C., Okorie, J.M., & Onyia O.F. (2018). Calcium Carbide in Ripening of Plantains and Bananas: Effects on Protein, Selected Vitamins and Mineral Contents, *Archives of Biological Sciences*, 14(2):230-241

Okonkwo, J.N., Nwosu, C.D., & Ezeanyika, L.U.S. (2020). Evaluation of cassava effluent as a ripening agent for banana and plantain. *Nigerian Journal of Biochemistry and Molecular Biology*, 35(2), 89–96.

Okorie, A.U., & Onochie, C.C. (2018). Effect of unripe wild mango as a ripening agent. *Nigerian Journal of Agriculture, Food and Environment*, 14(3), 45–50.

Okorie, A.U., Nwachukwu, A.M., and Mba, C.E. (2023). Unripe wild mango pulp as a natural ripening agent: Impact on proximate and sensory qualities of Musa spp. *West African Journal of Food and Nutrition*, 19(2), 34–41.

Okoye, J.N., Njoku, N.E., & Okeke, C.A. (2023). Residual toxicity of calcium carbide-ripened fruits: A review of public health concerns. *African Journal of Food Science and Technology*, 14(1), 12–19.

Olubiyo, G.T., Obochi, V.U., Edogbanya, P.R.O., Olubiyo, C.K., Iyeh, V.A., Obaje, J.O., Matthew, E.O., & Obaje, M. (2022). Evaluation of the effect of calcium carbide as a ripening agent on the nutritional value and heavy metal content of banana and orange. *Nigerian Agricultural Journal*, 53(3), 16.

Orok, E., Okeke, U., Williams, T., Adeniyi, F., Ikpe, F., & Mbang, F.O. (2024). Survey of knowledge on calcium carbide use in fruit ripening and associated health risks among fruit sellers and consumers in Ado-Ekiti Nigeria. *Discover Public Health,* 21, 28. https://doi.org/10.1186/s12982-024-00149-2

Pathak, N., Singh, A., & Singh, S. (2017). Comparative study of calcium carbide and ethylene ripened banana (*Musa sapientum* L.) fruits for nutritional and physicochemical parameters. *International Journal of Food Science and Nutrition*, 2(4), 14–19.

Quettier-Deleu, C., Gressier, B., Vasseur, J., Dine, T., Brunet, C., Luyckx, M., Cazin, M., Cazin, J.-C., Bailleul, F., & Trotin, F. (2000). Phenolic compounds and antioxidant activities of buckwheat (*Fagopyrum esculentum* Moench) hulls and flour. *Journal of Ethnopharmacology, 72*(1–2), 35–42. https://doi.org/10.1016/S0378-8741(00)00196-3.

Rahman, M.A., Rahman, M.M., & Hoque, M.A. (2018). Effect of chemical and natural ripening on the biochemical composition of banana (*Musa sapientum*). *Journal of Food Quality*, 2018, 1–7. https://doi.org/10.1155/2018/2971463

Salgado, N., Agudelo, C., & Gómez, R. (2023). Oxalate in foods: Extraction conditions, analytical issues, and dietary implications. *Nutrients*, 15(3), 551. https://doi.org/10.3390/nu15030551

Saranraj, P., & Sivasakthi, S. (2018). Changes in biochemical composition of banana during ripening and storage. *International Journal of Microbiology Research*, 9(5), 1038–1043.

Seymour, G.B., Østergaard, L., Chapman, N.H., Knapp, S., & Martin, C. (2013). Fruit development and ripening. *Annual Review of Plant Biology*, 64, 219–241. https://doi.org/10.1146/annurev-arplant-050312-120057

Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects – A review. *Journal of Functional Foods*, 18, 820–897. https://doi.org/10.1016/j.jff.2015.06.018.

Singh, R., & Janes, M. (2021). *Artificial fruit ripening: Health concerns and regulatory perspectives.* Food Control, 125, 107954. https://doi.org/10.1016/j.foodcont.2021.107954

Singleton, V.L., Orthofer, R., & Lamuela-Raventos, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology*, 299, 152–178.

Sojinu, O.S., Olowookere, M.A., & Akinola, O.O. (2021). The implications of ripening agents on chemical and nutritional characteristics of fruits. *Journal of Food Science and Nutrition, 8*, 123–135.

Stone, H., and Sidel, J.L. (2004). *Sensory Evaluation Practices* (3rd ed.). Academic Press.

Tanumihardjo, S.A. (2011). Vitamin A: Biomarkers of nutrition for development. *The American Journal of Clinical Nutrition*, 94(2), 658S–665S. https://doi.org/10.3945/ajcn.110.000075

Ugbeni, O.C., Adewale, O.E., & Chukwu, O. (2023). Calcium carbide–ripened plantain induced alterations in biochemical parameters: an experimental study. *Journal of Food Safety and Public Health, 12*(2), 45–57.

Ugbeni, O.C., Ijah, U.J.J., & Orjiakor, P.I. (2023). Chemical ripening of plantain using calcium carbide: Effects on nutritional composition and potential health hazards. *Journal of Food Quality*, 2023, 1–9. https://doi.org/10.1155/2023/9925617.

Wills, R.B.H., Golding, J.B., & McGlasson, W.B. (2019). *Postharvest: An introduction to the physiology and handling of fruit and vegetables* (7th ed.). CABI Publishing. https://doi.org/10.1079/9781786391483.0000.

World Health Organization (WHO). (2022). *Food safety risk assessment of chemical contaminants in fruits and vegetables*. Geneva: WHO Press.

Zou, F., Ojinnaka, C.S., & Onyeka, K. (2022). The valorization of banana by-products: nutritional and functional perspectives. *Heliyon, 8*(3), e08990. https://doi.org/10.1016/j.heliyon.2022.e08990